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# An Overview of U.S. and Canadian Experience with European Mass Burning Waterwall Incinerator Systems

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Xenia, OH

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# AN OVERVIEW OF U.S. AND CANADIAN EXPERIENCE WITH EUROPEAN MASS BURNING WATERWALL INCINERATOR SYSTEMS

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## FOREWORD

While the use of mass burning waterwall incinerators has gained wide acceptance throughout the world, i.e., approximately 350 operating units representing a design capacity of 110,000 tons per day (TPD), this concept of resource recovery for municipal solid waste (MSW) has only recently received enthusiastic acceptance here in the United States. While it has taken 14 years to establish nine U.S. and two Canadian mass burning waterwall facilities (representing total plant capacity of 8,114 TPD), the next 4 years will see an additional 16,000 TPD plant capacity become operational with numerous additional cities initiating plans for such systems. In anticipation of this accelerated demand, the Environmental Protection Agency (EPA) contracted with SYSTECH Corporation to present a technical overview of the operating and maintenance learning experiences at each of the 11 mass burning resource recovery sites in North America.

EPA Laboratory Director

## ABSTRACT

This report presents a detailed overview of the operating and maintenance learning experiences of each of the 11 mass burning waterwall resource recovery plants currently operating in North America. Since 5 of the 11 plants are of European design, a comparison of U.S. versus European operational experience is made. Also, in order to assist municipal planners and facility designers considering new mass burning resource recovery projects, a summary of the learning experiences (including recommendations) is provided. Finally, a brief status overview of the mass burning waterwall systems in various stages of planning, design, and/or construction is discussed.

CONTENTS


Disclaimer . . . . . ii
Foreword . . . . . iii
Abstract . . . . . iv
Acknowledgments . . . . . vi

1. Introduction . . . . . 1
   General . . . . . 1
   The mass burning concept . . . . . 1
2. United States and Canadian Operational Experience . . . . . 4
   Chicago Northwest (Illinois) . . . . . 7
   Harrisburg (Pennsylvania) . . . . . 11
   Saugus (Massachusetts) . . . . . 13
   Nashville (Tennessee) . . . . . 16
   Oceanside (Town of Hempstead, Long Island, New York) . . 19
   Braintree (Massachusetts) . . . . . 22
   Navy Public Works Center (Norfolk, Virginia) . . . . . 24
   Norfolk Naval Shipyard (Portsmouth, Virginia) . . . . . 27
   Hampton (Virginia NASA-USAF) . . . . . 29
   Montreal (Quebec) . . . . . 31
   Quebec (Quebec) . . . . . 33
   Observations and recommendations . . . . . 35
   Future mass burning facilities . . . . . 37
      Pinellas County (Clearwater, Florida) . . . . . 37
      Gallatin (Tennessee) . . . . . 39
      Westchester County (New York) . . . . . 39
      Portland (Oregon) . . . . . 40
      San Francisco (California) . . . . . 40
      North Andover (Massachusetts) . . . . . 40
      128 West Project (Massachusetts) . . . . . 41
      Onondaga County (Syracuse, New York) . . . . . 41
      Brooklyn Navy Yard (Brooklyn, New York) . . . . . 41
      Providence (Rhode Island) . . . . . 42
   Legal, financial, and institutional factors . . . . . 42
      The future of mass burning in the United States . . 43

Bibliography . . . . . 44

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# SECTION 1

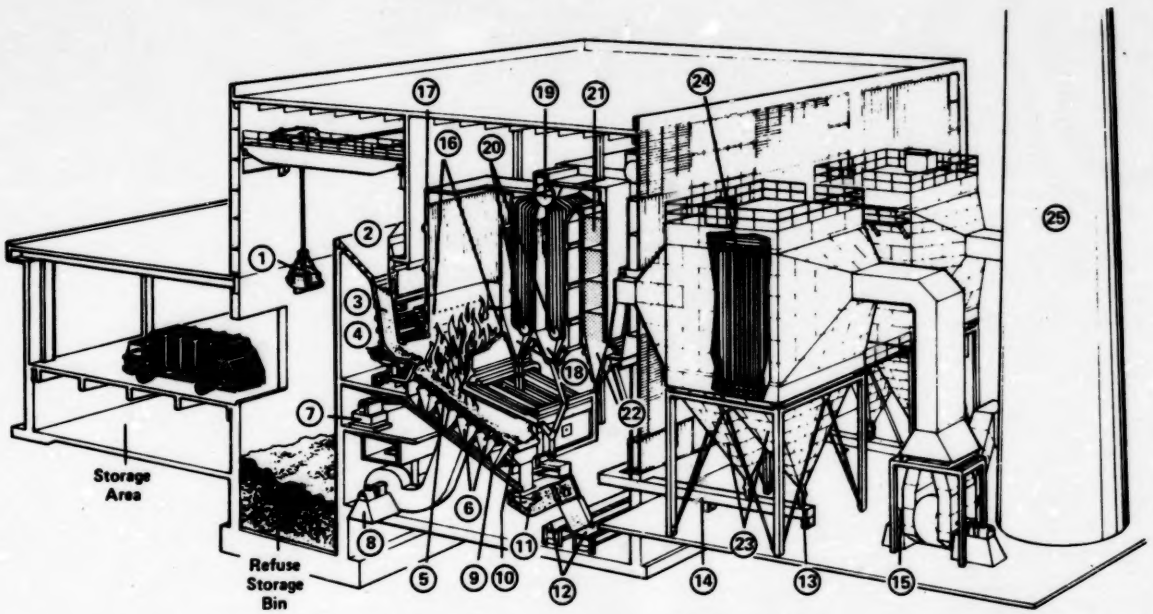
# INTRODUCTION

## GENERAL

While mass burning of municipal refuse in refractory wall incinerators has been practiced in the United States and Europe since the late 1800s, it was not until 1954 in Berne, Switzerland, that the first waterwall furnace/boiler system was introduced. This facility was unique and had much design foresight in that emphasis was placed on energy recovery rather than waste disposal. Steam produced in the Berne plant was used for (1) generation of electricity, (2) export to industry for process heat, and (3) export to a local district heating network. In the 28 years since this innovative plant was brought into service, the mass burning waterwall incinerator resource recovery system has proliferated throughout the world. While there are currently approximately 350 operating units throughout the world representing an installed capacity of 110,000 tons per day (TPD), in North America there are only 29 operating units (21 units located in the U.S.) with an installed capacity of 8,114 TPD. The U.S. installed capacity represents less than 2 percent of the 180 million tons per year (TPY) of municipal solid waste (MSW) currently generated in the United States. With the advent of escalating landfill and energy costs and the availability of such a large untapped and virtually inexhaustible resource such as MSW, municipal planners are now enthusiastically looking to the mass burning waterwall incinerator concept as both an environmentally and economically viable alternative. While it took 14 years to bring 8,000 TPD into operation in the United States, the next 4 years will see an additional 16,000 TPD come on line with numerous additional cities initiating plans for mass burning resource recovery systems. In view of this apparent accelerated demand, it is the intent of this article to assist municipal planners and facility designers by presenting a technical overview of the operating and maintenance learning experiences at each of the nine United States and two Canadian mass burning resource recovery sites.

## THE MASS BURNING CONCEPT

The mass burning waterwall incinerator system is commonly referred to as European technology since the waterwall furnace design was introduced in Europe and subsequently developed by two European firms (Josef Martin Feuerungsbau GmbH and Von Roll Ltd). These two firms account for 326 (approximately 93 percent) of all the operating units in the world. A typical illustration of these European waterwall incinerators is shown in Figure 1. In this illustration, as-received refuse is transferred from a receiving pit (typically sized with 3 to 5 days firing capacity) into the furnace feed




1. Crane
2. Feed Hopper
3. Feed Chute
4. Feeder Rams
5. Reverse Reciprocating Stoker
6. Undergrate Air Plenum Chambers
7. Hydraulic Pump
8. Forced Draft Fan
9. Automatic Siftings Removal Systems
10. Residue Roller
11. Residue Discharger
12. Residue Conveyors
13. Rotary Valve
14. Fly Ash Conveyor
15. Induced Draft Fan
16. Overfire Air Nozzles
17. Waterwalls (Welded Panel Const.)
18. Boiler Fly Ash Hoppers
19. Steam Drum
20. Bottom Boiler Drum
21. Economizer
22. Economizer Fly Ash Hopper
23. Fly Ash Hoppers
24. Electrostatic Precipitators
25. Stack

Figure 1. A typical waterwall incinerator.
(courtesy of UOP, Inc.)

hopper by means of an overhead bridge crane with a grapple. The feed chute is kept full to ensure a continuous supply of refuse and to maintain a furnace air seal. From the hopper, wastes are fed at load controlled rates (usually at 12- to 16-in. bed depths) by means of an inclined grate system. The grate system serves to agitate the refuse, permit controlled introduction of underfire air through the grate, transport the refuse through the furnace section, and finally deposit the ash residues into a wet sump. The wet ash sump also serves as a furnace air seal. Overfire air ports on the front and rear walls (and sometimes the sidewalls) ensure that proper combustion kinetics are maintained and that primary burnout occurs within the lower two-thirds of the furnace. The waterwalls are typically welded membrane, tube and tile, or tubes spaced from the refractory wall. The lower regions of the furnace wall are commonly protected from slagging, corrosion, and erosion by ceramic plates and/or bricks (adjacent to the grate) and a refractory coating (up to approximately one-half the furnace height). The flue gases leave the furnace and pass through the boiler section (often multiple pass). In some applications a superheater tube section is included to facilitate electrical power generation or transmission of steam over extended distances. Economizers are often included to improve boiler efficiency. Boiler efficiencies are typically 62 percent without an economizer and 68 percent with an economizer. The combustion gases leaving the boiler sections are passed through air pollution control equipment (usually electrostatic precipitators [ESPs]) and exhausted to the atmosphere through a stack. The ash residue is typically removed from the wet sump via a drag conveyor and in some cases is further processed for metal recovery.

The waterwall incinerator units range in size from 55 TPD to 1320 TPD (which is the largest unit in the world, located at the Ivry plant in Paris). Over the years, the plant capacities have increased from 100 to 200 TPD in the 1950s, 300 to 600 TPD in the 1960s, to the current plant designs which range from 1500 to 3000 TPD.

## SECTION 2

## UNITED STATES AND CANADIAN OPERATIONAL EXPERIENCE

Mass burning waterwall incinerators were introduced into the United States with the operation start up of the Navy Public Works Center facility (Norfolk, Virginia) in May 1967. There are now nine U.S. and two Canadian mass burning waterwall systems in operation. Of these 11 systems, 5 are of European design, i.e., Chicago Northwest and Harrisburg, Pennsylvania, are Josef Martin systems; and Montreal, Province of Quebec; Quebec, Province of Quebec; and Saugas, Massachusetts, are Von Roll systems. These five plants represent 70 percent of the installed 8,114-TPD capacity and have processed 80 percent of the 13,989,000 tons of MSW consumed in mass burning waterwall incinerators to date. Table 1 summarizes the design and operational data record for these plants. In comparing the U.S. design with European design plants, it can be observed that the European design plants typically have a 75 to 85 percent availability vs a 50 percent availability on four of the six U.S. design plants. This lower availability in the U.S. design plants can primarily be attributed to the frequent need to service grates and/or boiler tubes.

Introduction of the "proven" European mass burning technology into the United States has not been without difficulties. Some of the reasons for these difficulties are: (1) difference in waste composition, (2) scale-up to larger capacity units, and (3) failure of the U.S. systems to completely incorporate all of the "proven" European technologies into their designs.

In reviewing the difference between European and U.S. wastes (see Table 2) it can be observed that U.S. wastes contain 50 percent more paper, 25 percent more plastics, and a slightly higher dry heating value. This difference in waste composition necessitates that designers incorporate adjustments in their grate area and furnace volume heat release rates and that they anticipate greater potential for high temperature chloride corrosion of boiler tubes.

Because of the large quantities of municipal refuse concentrated in the cities and suburbs of the United States, it was necessary for plant designers to increase the unit capacity of the mass burning waterwall systems. This scale-up from 300 to 600 TPD and larger unit capacities resulted in a number of furnace and boiler problems which were subsequently resolved in the ensuing years of operation.

Prior to introduction into the United States, the European mass burning waterwall systems had clearly demonstrated a highly reliable, ruggedized,

TABLE 1. SUMMARY OF THE OPERATIONAL U.S. AND CANADIAN MASS BURNING WATERWALL SYSTEMS

| Location | Placed in service | Design capacity (TPD) | Current capacity (TPD) | Number of lines | Total tons processed | Availability (%) | Steam output (lb/hr) | Cost (1981) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Capital ($ millions) | Unit ($/TPD) |
| Saugus, MA* | November 1975 | 1200 | 1050 | 2 | 2,000,000 | 77 | 370,000 | 88.5 | 73,750 |
| Chicago, IL† | September 1970 | 1600 | 1200 | 4 | 3,700,000 | 75 | 330,000 | 57.0 | 35,635 |
| Harrisburg, PA† | October 1972 | 720 (plus 14 TPD sludge) | 580 | 2 | 1,000,000 | 85 | 130,000 | 17.6 | 24,437 |
| Nashville, TN | August 1974 | 720 | 530 | 2 | 850,000 | 50 | 100,000 (or 14 tons refrig.) | 41.6 | 57,735 |
| Oceanside, NY | June 1974 and June 1977 | 750 | 450 | 3 | 700,000 | 50 | 60,000 (plus 2480 kW electricity) | 24.8 | 33,060 |
| Braintree, MA | May 1971 | 384 | 250 | 2 | 485,000 | 85 | 60,000 | 6.6 | 17,135 |
| Navy Public Works Center Norfolk, VA | May 1967 | 180 | 140 | 2 | 575,000 | 50 | 45,000 | 6.2 | 34,532 |
| Norfolk Naval Shipyard Portsmouth, VA | August 1977 | 160 | 50 | 2 | 50,000 | 40 | 25,000 | 6.7 | 42,000 |
| Hampton, VA (NASA, USAF) | September 1980 | 200 | 240 | 2 | 71,300 | 85 | 62,000 | 14.4 | 71,760 |
| Montreal, Canada* | September 1970 | 1200 | 975 | 4 | 3,100,000 | 85 | 360,000 | 35.5 | 29,556 |
| Quebec City, Quebec, Canada* | June 1974 June 1975 | 1000 | 650 | 4 | 1,458,000 | 75 | 130,000 | 59.4 | 59,400 |

* Von Roll system
† Josef Martin system

TABLE 2. COMPOSITION AND HEATING VALUE OF TYPICAL MSW IN EUROPE AND THE UNITED STATES

| Constituents | Composition by weight (percent) A Europe† | Composition by weight (percent) B U.S.† | Higher heating value (dry), Btu/lb* C | Higher heating value average (dry), Btu/lb D Europe§ | Higher heating value average (dry), Btu/lb E U.S.§ |
|---|---|---|---|---|---|
| Food waste | 19.1 | 8.9 | 8,484 | 1,616 | 751 |
| Textiles | 2.7 | 3.4 | 7,652 | 205 | 256 |
| Paper | 33.6 | 49.8 | 7,572 | 2,545 | 3,771 |
| Plastics | 3.5 | 4.4 | 14,368 | 509 | 632 |
| Wood | 2.6 | 6.3 | 8,613 | 221 | 543 |
| Street sweepings, garden waste | 5.1 | 5.4 | 6,000 | 308 | 321 |
| Stones, dust, metals, fines | 33.4 | 21.8 | 3,000 | 1,003 | 655 |
| | 100.0 | 100.0 | | 6,407 | 6,929 |

Sources of data:

* Average of data - American Standards Institute, American National Standard 2228 - Incineration, proposed standards. New York, NY, 1975.

† Europe: Average of data - Battelle Columbus Laboratories. European Refuse-fired Energy Systems. Evaluation of Design Practices, Vol. 2., U.S. Environmental Protection Agency, Office of Water and Waste Management, Washington, DC, 1979.

U.S. : Respondents to questionnaire.

§ Europe: Column D = Column A × Column C

U.S. : Column E = Column B × Column C

inclined reciprocating grate system. Also, air-cooled refractory bricks and the use of silicon carbide coating protecting the lower furnace walls was a generally accepted practice. Another accepted design practice was the avoidance of superheater tube corrosion by locating the superheater in a boiler pass, protected from the high temperature flame radiation. Incorporation of these design features into the U.S. designed systems could have saved considerable operational and maintenance problems and significantly improved plant availability.

Further details on the current operational status and maintenance problems associated with each of the nine U.S. and two Canadian facilities are presented in the following paragraphs. The information was obtained by interviewing the plant superintendent. In each case, the plant superintendent was asked to relate operational and maintenance experiences and to respond to the question "If you were to redesign your plant, what would you do differently?" The following discussion represents the results of these interviews.

CHICAGO NORTHWEST (ILLINOIS)

The Chicago Northwest mass burning waterwall incinerator is unique from a number of different viewpoints. At a design capacity of 1600 TPD it is the largest mass burning waterwall incinerator facility in North America. It also has processed more MSW (3.7 million tons as of December 1, 1981) than any other incinerator in the United States.

Other firsts include the first installation of an ESP on an MSW incinerator, the first European (Martin) waterwall system in the United States (became operational in September 1970), and the site at which the Environmental Protection Agency (EPA) mass burning emissions standards were generated. A summary of the facility's design and operational data is as follows:

| | |
|---|---|
| Placed in service: | September 1970 |
| Design capacity: | 1,600 TPD |
| Current throughput: | 1,200 TPD |
| Availability: | 75 percent (1 of 4 units is continually on standby) |
| Total amount processed: | 3,700,000 tons (as of December 1, 1981) |
| Receiving: | 10,000 $yd^3$ with 3 each 5 $yd^3$ cranes |
| Number of lines: | Four each |
| Grates: | Martin reverse acting stoker grate |

| | |
|---|---|
| Boilers: | Four Walther boilers, each having a maximum continuous rating (MCR) of 110,000 lb/hr (275 psig and 414°F) and a peak capacity of 135,000 lb/hr, welded membrane wall, and five boiler tube passes with an integral economizer |
| Boiler efficiency: | 67 percent |
| Auxiliary burners: | Two each gas fired burners per boiler with a total steaming capacity of 110,000 lb/hr |
| Pollution control: | Four each Rothemuehle-Walther Company ESPs (2 cell, 97 percent efficient) |
| Current emissions: | 0.03 gr/scfm corrected to 12 percent $CO_2$ |
| Product: | 75,000 lb/hr (average) saturated steam supplied to Brach Candy |
| Capital cost: | $23 million (1969) |
| Unit cost: | $35,635/TPD (1981) |
| Number of employees: | 83 |

Throughout 11 years of operation, the plant has continued to operate with very little unplanned down time. This excellent operational record is primarily due to a well planned preventive maintenance program (discussed in detail later). An overview of the operating and maintenance problems with associated learning experiences at this facility follows.

1. Receiving: The 10,000 $yd^3$ receiving pit is too small. The pit should be at least 50 percent larger. Also, the drains in the pit are generally nonfunctional. Future pit drains should have accessible plumbing to permit pneumatic blowing or rodding to clear the drain. Also, the cranes should be remotely operated with a programmable stacking capability. Remote control provides greater operator flexibility and safety. Programmable control frees the operator for other duties and reduces crane maintenance requirements. Chicago Northwest is currently studying the installation of remote crane control. Since there is a rapid turnover of waste, there have been no pit fires of any significance.

2. Refuse hopper: The water cooled refuse hopper and feed chute have performed well. There have been very few jams in the 3-ft × 8-ft feed chute.

3. Grates: The Martin reverse acting reciprocating stoker has performed well. After 11 years of operation (approximately 70,000 hours of operation), 60 percent of the grate bars are still original. This extended life was achieved by periodic cleaning of

the grates and expansion joints and rotating the grate bars (inlet to outlet).

4. Refractory wall: The furnace walls are coated with a castable silicon carbide refractory (1 in. thick) approximately one-half the height of the furnace. This protective coating coupled with careful control of overfire/underfire air and grate bed refuse depth has essentially eliminated tube failure problems in the furnace section.

   Slagging problems have been minimal. The water cooled header immediately adjacent to the grate has served to minimize slagging in this area.

5. Tube corrosion/erosion: Tube failures have primarily occurred in the convective tube section in those areas immediately adjacent to the soot blowers. These failures have been minimized to approximately 2 per year by installing 410 stainless steel tube shields at those tube locations subjected to high velocity steam impingement from the soot blowers. Soot blowing occurs once each day and is activated when the economizer exit temperature increases approximately 50°F (500°F to 550°F). Tube erosion in the convective section is 1 mil/yr. Tube corrosion per se has not been a problem. This success can primarily be attributed to careful control of furnace combustion conditions, i.e., a 12- to 18-in. grate refuse bed depth, 80 to 85 percent excess air (5 in. of water on the grate overfire air jets and 10 to 12 in. of water pressure on the overfire jets in the midfurnace location), and periodic maintenance.

6. Economizers: The original economizers are still in service and performing well, i.e., 228°F water inlet and 405°F water outlet at a gas exit temperature of 414°F).

7. Electrostatic precipitators: Performance of the ESPs has been good. Since the few problems experienced with the ESPs have been weather related, future installations would do well to consider enclosing them. This would eliminate the need for weatherproof motors and heated hoppers and generally would facilitate maintenance operations.

8. Ash handling system: From a maintenance point of view, the ash handling system is the most labor intensive area in the plant. The pan conveyor used to transport the bottom ash to the ash storage hoppers requires continual maintenance. The 1600 pins, wheels, and bushings must be continually rebuilt. Also, the conveyor supports have been strengthened and the spill plates widened. An expandable ash discharger is also currently under consideration to eliminate jams. Future ash conveying systems should consider the use of drag conveyors or, more preferable, ash pits (with no conveyors) with a crane bucket removal capability.

9. Controls: Operation of the "mass fired" combustion units at the Chicago Northwest waste-to-energy facility is semi-automatic. Due to the heterogeneous nature and variable moisture content of MSW, full automatic control is not always practical or desirable. This can best be illustrated when considering what would happen if the incinerator were on automatic control with a drop in steam pressure calling for an increase in both air flow and input of MSW. If the drop in steam pressure resulted from excessively wet MSW, a subsequent increase in air flow and MSW feed would result in the fire being extinguished. Operators at the Chicago Northwest waste-to-energy facility handle this problem by maintaining close communication among the crane operator, the boiler operator, and control room personnel. When the crane operator notices the presence of wet MSW, he will start to mix the receiving pit material and at the same time notify the control room. The control room operator will monitor his instrument readings more closely and also inspect the fires more frequently. If necessary, a change in overfire air will be made to facilitate drying the MSW fuel. In summary, the controls should be kept simple, and semi-automatic operations should be maintained with well trained and knowledgeable operators.

10. Co-generation: Since the Chicago Northwest incinerator facility is currently condensing an average of 185,000 lb/hr of steam, consideration is being given to co-generation. A recent preliminary study indicated that installation of a 2.5 MW and a 1.0 MW turbogenerator system (operating at 250-psi inlet and 15-psi back pressure) selling electricity at $.04/kWh will result in a 2.5-yr payback. The low pressure steam from the turbogenerator would subsequently be used to heat and cool (lithium bromide air conditioning system) the plant.

11. Auxiliaries: Other factors which Chicago Northwest have found to be vital in facilitating the successful operation of a mass burning facility are (1) the use of auxiliary burners to slowly (5 to 6 hours) bring the waterwall incinerator up to temperature after it has been down for repairs, (2) the use of SCR speed control on cooling tower fan motors, (3) the use of a boiler feedwater treatment system consisting of a two-stage mixed bed demineralizer and degasser with condensate polishing and pH control (10.5 to 11), (4) the use of double external drive shafts to permit the use of either steam or electric drives, and (5) a fully equipped maintenance shop with skilled personnel to run it.

Preventive maintenance has been found to be one of the primary reasons for maintaining high availability of the incinerators at the Chicago Northwest resource recovery facility. Every 6 to 9 months, one of the four incinerators is taken off line for major preventive maintenance. During this time, grates are cleaned, serviced, and rotated; tubes are cleaned; refractory is repaired; and other miscellaneous tasks are performed.

Eleven years of successful operation at the Chicago Northwest resource recovery facility attest to the fact that waterwall mass burning incineration can be successful when implemented with a well planned preventive maintenance program coupled with well trained and knowledgeable operators.

HARRISBURG (PENNSYLVANIA)

The Harrisburg steam generating and resource recovery facility is another example of proven European mass burning technology transferred to the United States. The design of this facility is based upon the grate and boiler system supplied by the Josef Martin Company of Munich, Germany. This firm has a total of 169 units in operation or under construction with an accumulated burning capacity of 52,500 TPD. Of the total, 116 (69.0 percent) include energy recovery. Specific information as related to the design and operation of the Harrisburg plant is as follows:

| | |
|---|---|
| Placed in service: | October 1972 |
| Design capacity: | 720 TPD (refuse), 14 TPD (MSW sludge) |
| Current throughput: | 580 TPD of refuse (81 percent of capacity) |
| Total amount processed: | 1 million tons (November 14, 1980) |
| Average availability: | 80 percent (October 1, 1980, to October 1, 1981) |
| Receiving: | 6720 $yd^3$ (40-hr firing capacity) |
| No. of lines: | Two |
| Grates: | Martin reverse acting stoker grate |
| Boilers: | Two each Walther boilers with each boiler rated at 95,500 lb/hr (260 psig and 525°F) maximum continuous steam capacity, welded membrane wall, and five boiler tube passes with an integral economizer |
| Boiler efficiency: | 64.5 percent |
| Auxiliary burners: | Two each oil fired burners per boiler with a capacity of 120,000 lb/hr |
| Pollution control: | Two each Rothemuehle-Walther ESPs (93 to 97 percent collection efficiency) |
| Current emissions: | 0.10 gr/scfm corrected to 50 percent excess air |

| | |
|---|---|
| Product: | Steam, exporting up to 130,000 lb/hr for downtown heating |
| Capital cost: | $8.3 million (1972) |
| Unit cost: | $24,437/TPD (1981) |
| Number of employees: | 75 |

The Harrisburg Resource Recovery Facility recently completed 9 years of operation and the processing of over 1 million tons of refuse. Throughout this time, the plant has continued to operate with scheduled and unscheduled down time for boiler tube replacement and other minor problems. An overview of some of the maintenance and operational problems experienced at this facility follows.

1. Receiving: The 6720-$yd^3$ receiving pit is too small. The pit should be at least two to three times the present capacity, i.e., 5- to 7-day firing capacity (both boilers).

2. Cranes: In the past, there have been some major fires in the receiving pit. Since the cranes are designed to be operated immediately above the receiving pit, this presents a safety hazard to the crane operator. Future designs should incorporate a provision for moving the cranes off to the side of the receiving pit. Also, crane operation should be accomplished by remote control.

3. Refuse preprocessing: A steam driven shredder has been used to reduce oversized refuse and white goods. Since this shredder has experienced a number of fires, use of the shredder has been greatly reduced.

4. Grates: After 9 years of operations, 40 to 50 percent of the Martin stoker grate bars are still in service. Grate bar wear and burnout has been primarily in the middle and/or upper section of the grate (higher temperature areas).

5. Boiler: Boiler tube erosion and corrosion have been frequent problems at the Harrisburg facility. During the early months of operation, the facility was shut down on the weekends. These frequent shutdowns resulted in dew point corrosion in the economizer. This problem was subsequently eliminated by operating the boilers on a continuous basis. After 7 years of operation, the frequency of repairs on the economizer necessitated a complete replacement of the unit. Since this replacement, tube failures in the one economizer have again become a reoccurring problem (one tube failure per month). Investigations are under way to locate the cause of these failures and to identify a solution.

Corrosion and failure of the superheater tubes were originally occurring on a 6-mo cycle. After the material in the superheater tubes was changed to a higher strength chrome alloy and the wall thickness was increased to 0.220 in., the superheater tube replacement cycle has been extended to 2 years. Elimination of soot blowing in the superheat section has also been a factor in extending tube life.

Erosion of tubes has been evident on the furnace sidewalls (where the refractory has been worn away) and in the convective tube bank section.

6. Ash handling: The ash handling system is the most labor intensive operation in the Harrisburg Resource Recovery Facility. Handling of the ash has resulted in excessive conveyor wear (particularly the ESP screw conveyor) and dust. Also, truck drivers and trucks must be available on a three-shift basis.

   Future ash handling systems should incorporate the use of full flight (preferably horizontal) conveyors and/or an ash pit with sufficient capacity to permit all of the ash removal to be accomplished on the day shift.

7. Maintenance: Planned maintenance at the Harrisburg Resource Recovery Facility is currently scheduled for a 2- to 4-wk shutdown once each year. Unscheduled maintenance is currently requiring a down time of 40 to 80 hours per boiler per month.

SAUGUS (MASSACHUSETTS)

The Refuse Energy Systems Company (RESCO) resource recovery facility in Saugus, Massachusetts, represents an example of proven European mass burning technology transferred to the United States. The design of this facility was based upon Von Roll technology which had been successfully demonstrated in 157 plants (50,297 TPD total processing capacity) throughout Europe and Asia. Specific information related to the design and operation of the RESCO facility is as follows:

| | |
|---|---|
| Placed in service: | October 1975 |
| Design capacity: | 1200 TPD (average) 1500 TPD (maximum) |
| Current throughput: | 1160 TPD (92 percent of capacity) |
| Total amount processed: | 2 million tons (December 11, 1981) |
| Average continuous throughput since start-up: | 900 TPD |
| Availability: | 82 percent (most recent year) with 15 percent of down time unplanned |

| | |
|---|---|
| Receiving: | 6700-ton capacity |
| Number of lines: | Two each |
| Grates: | Von Roll reciprocating |
| Boilers: | Two each Von Roll designed boilers with each boiler having an MCR of 185,000 lb/hr (690 psig and 875°F) steaming capacity |
| Boiler efficiency: | Estimated at 70 percent |
| Auxiliary boilers: | Two each with each boiler rated at 110,000 lb/hr steam at 690 psig and 875°F (oil fired) |
| Product: | 280,000 to 300,000 lb/hr of steam |
| Pollution control: | Two each ESPs with a 99 percent efficiency |
| Current emissions: | 0.025 gr/scfm corrected to 12 percent $CO_2$ |
| Capital cost: | $40 million (1974) plus 11 million (1977) |
| Unit cost: | $73,750/TPD (1981) |
| Number of employees: | 55 |

Based upon the wide spread use of the Von Roll mass burning system throughout the world, the probability of successful introduction into the United States was quite high. However, numerous start-up problems forced the owners to invest an additional $11 million in equity (bringing the total facility cost to $51 million) to improve overall system performance. A summary of the problems experienced and the associated solution follows:

1. Receiving: The 6700 ton, 200 ft long, by 40 ft wide, by 100 ft deep receiving pit is too small. One of the two cranes must be dedicated to moving incoming material from the tipping areas to the ends of the pit so that space for dumping is continuously available to incoming trucks. Future plants of this size should be designed with at least a 10,000 ton capacity (or as large as economically feasible).

2. Cranes: As a result of the 24 hr/day, 7 day/wk usage, the original cranes experienced excessive brake wear and cable failures. Through design and operating changes, the cranes now operate with less than half the maintenance originally required.

3. Refuse preprocessing: The 6-$yd^3$ bucket on one of the cranes is so large that it prevents observing objects which could cause trouble in the incinerators. Segregation of these objects would be

facilitated in future designs through the use of larger receiving pits, smaller buckets, and closer visual inspection of incoming wastes. A shredder that was originally thought to be necessary to reduce bulky items prior to combustion was removed after 6 months when it became obvious that it was not needed.

4. Grates: During the first 6 weeks of start up, the original grates experienced excessive wear and material fatigue. These failures were diagnosed as improper metallurgy treatment. Wheelabrator and Von Roll subsequently redesigned the grate system utilizing an improved, high strength alloy; incorporated a roller configuration which reduces the hydraulic pressure required to activate the grates by 90 percent; and strengthened the under structure of the grate support system. This improved design and metallurgy has greatly improved grate performance.

5. Boilers: During the initial months of operation, excessive boiler tube corrosion, erosion, and sidewall slagging occurred. Subsequently, abnormal corrosion was greatly reduced by a change in tube metallurgy and by improved combustion. An analysis of the combustion zone immediately above the grate revealed that turbulence was not sufficient to ensure complete combustion of the gases. As a result, localized unburned gases with high carbon monoxide, reducing atmospheres, and high temperatures were impinging upon tube surfaces and causing corrosion. In an attempt to achieve complete combustion, excess air levels of 130 percent were maintained. Operation at this high excess air level achieved the desired completion of combustion of the gases in the lower portion of the furnace. However, the higher air velocities resulted in increased particle entrainment. In order to rectify this problem, a major furnace redesign was instituted. The front and rear furnace walls were modified (nosed inward above the grate), creating an area of high turbulence through which all of the combustion gases had to flow. Mixing of the combustion gases was further enhanced by installation of additional overfire air jets and optimization of the air flows as required to ensure complete combustion of the gases before they enter the boilers. This furnace modification has also permitted the excess air to be reduced to 75 to 80 percent with the resulting benefit of reduced particle entrainment and tube erosion.

   Slagging along the sidewalls (immediately adjacent to the grate) was significantly reduced through optimization of refuse feed rate, grate speed, and improved air flow and mixing. Future designs could incorporate water cooled refractory covered walls extending below the grate. Air cooled refractory panels (1 meter × 1 meter) with 400 air injection holes per panel could also be utilized immediately adjacent to the burning refuse on the grate.

6. Ash handling: The ash removal system, composed of a quench tank and chain link conveyor to the materials recovery building, has been found to be very labor intensive. Ash is removed on a 3-shift

basis, requiring a continual commitment of trucks and operators. Future plant designs could incorporate an ash pit inside the building with sufficient capacity to allow ash removal to be accomplished on the day shift.

7. Maintenance: The facility is currently operating at a planned 80 percent availability. While unplanned boiler shutdowns have been rare at RESCO, operating both boilers continuously is not the most effective maintenance scenario. A plant of this size should have three 500- to 750-TPD boilers. This would permit maintenance of one boiler while the other two were operating plus the ability to handle peak loads without overloading the equipment.

Part of the reason for the start-up problems at the RESCO plant was the scale-up of the Von Roll system to the 600-TPD unit capacity. The largest Von Roll unit sizes previously designed were 300 TPD. This doubling of capacity imposed different design and operating requirements than those previously documented in existing European facilities.

In summary, RESCO has served as a commercial R&D Center for successfully demonstrating that European technology can be adapted to the conditions in the United States. Lessons learned at this facility should be an invaluable guide in the design of future mass burning facilities.

NASHVILLE (TENNESSEE)

The Nashville Thermal Transfer Corporation (Thermal), a nonprofit corporation, is the owner and operator of Nashville's 400-TPD mass burning resource recovery facility. After some major start-up problems and facility modifications, Thermal has, for the past 5 years, reliably provided steam to Nashville's central business district (consisting of 28 buildings) and disposed of 25 percent of Nashville's solid waste. Specific information relative to the design and operation of Nashville Thermal is as follows.

| | |
|---|---|
| Placed in service: | August 1974 |
| Design capacity: | 720 TPD (360 TPD per incinerator) |
| Current throughput: | 530 TPD (per incinerator) |
| Total amount processed: | 850,000 tons (as of November 1981) |
| Average continuous throughput since start-up: | 320 TPD |
| Availability: | 50 percent |
| Receiving: | 5400 $yd^3$ (3-day supply) |
| Number of lines: | Two each |

| | |
|---|---|
| Grates: | Ram feed plus a Detroit stoker, three-section, reciprocating grate |
| Boilers: | Two each Babcock & Wilcox multipass welded membrane boilers with a superheater and an integral economizer. Each boiler is rated at 109,000 lb/hr (MCR), 135,000 lb/hr (peak), 400 psig, and 600°F. Auxiliary gas/oil fired burners are available in each boiler with a combined capacity of 135,000 lb/hr. |
| Boiler efficiency: | 67.5 percent |
| Auxiliary boiler: | One each Combustion Engineering fossil fuel fired standby boiler rated at 125,000 lb/hr |
| Pollution control: | Two each ESPs manufactured by American Air Filter Company |
| Current emissions: | 0.007 gr/scfm corrected to 12 percent $CO_2$ |
| Product: | 100,000 lb/hr steam and/or 14,000 tons of refrigeration |
| Capital cost: | $24.5 million ($15 million in 1974 plus $9.4 million in 1976/1977) |
| Unit cost: | $57,735 (1981)/TPD (design) |
| Number of employees: | 37 |

Nashville Thermal has experienced numerous plant modifications during its 7-yr operational history. Primary modifications have centered around three areas: (1) refuse feeding and grate performance, (2) boiler tubes, and (3) emission control. The following paragraphs provide a brief overview of the problems encountered and the solutions implemented.

1. Grates: Grate replacement is required on the average of four times per year (2,000 to 2,500 operating hours per set of grates). Several design changes have been implemented in order to improve grate performance. They include the following:

   A. Replacement of the cast iron grates with chrome-nickel alloy grates with bolt fasteners. These grates have currently accumulated 3200 hours with minimal wear and breakage.

   B. Installed a dual grate drive on the first two burning grates.

   C. Isolated the siftings removal drive from the grate drive.

D. Redesigned and rebuilt the grate support structure.

E. Installed baffles to properly distribute the underfire air through the grate.

2. Boiler tubes: Incinerator boiler tube wastage has been the most dominant ongoing problem at Nashville Thermal. Waterwall tubes have failed in all parts of the furnace from 11,000 to 15,000 hours. Superheater life has not exceeded 10,000 hours, and each boiler is currently operating with its fourth superheater. The convective bank was replaced once on each boiler in 1978, and one of the boilers is currently undergoing its second installation. Tube life of the convective bank has typically ranged from 11,000 to 13,500 hours. It is worth noting that the economizer has not experienced any corrosion since start-up. Soot is blown daily in the economizers. Much of the tube failures can be directly attributed to nonuniform feeding of refuse onto the grate, inadequate excess air and turbulence to ensure complete combustion, and consistently firing the incinerators at the maximum steam output design capacity. The aforementioned conditions resulted in reducing atmospheres, long flame lengths, and excessive flame impingement on boiler surfaces; all conducive to promoting corrosion. Also, since the superheater tubes are exposed to the high temperature flame radiation, the tube surfaces experience conditions (excessive temperatures) conducive to chloride corrosion. Nashville Thermal has attempted to correct the accelerated boiler tube failure problem by implementing the following design changes.

A. Addition of silicon carbide refractory to the studded walls to a height of 20 feet above the grate (furnace height 50 to 55 feet).

B. Installation of a hydraulic ram feeder with appropriate control loops to regulate the ram feed rate to achieve desired uniform feeding and fuel bed depths.

C. Reduction of the boiler soot blowing frequency from once per day to once every 4 to 6 days, determined by monitoring boiler exit gas temperature.

D. Increase of tube thickness by 0.015 to 0.040 in. (depending upon location) and metallizing the tubes with aluminum.

E. Replacement of steam turbine driven induced draft (ID) fans with motor driven fans. This modification ensured adequate furnace draft.

F. Planned installation of a new overfire air system which will improve turbulence and combustion and will enable achievement of the desired 84 percent excess air level.

3. Pollution control: Replacement of the original low pressure loss, moderate efficiency, wet scrubbers (which were experiencing excessive corrosion and particulate emissions) with ESPs has essentially solved the air pollution control problem. With the exception of hopper pluggages (due to improper weld joints to seal out water migration), the ESPs have performed well with emissions well under the EPA limit of 0.08 gr/scfm corrected to 12 percent.

The Nashville Thermal experience has demonstrated the need for providing sufficient plant capacity and number of units such that maintenance is facilitated and combustion conditions conducive to corrosive environments are minimized. It further indicates the need for designs ensuring even feeding and uniform refuse bed depth on the grate coupled with sufficient excess air and turbulence (underfire and overfire air) to guarantee complete combustion and elimination of flame impingement on tube surfaces. Consideration should also be given to protecting the superheater tubes from the high temperature flame radiation by placing them in the second or third pass.

OCEANSIDE (TOWN OF HEMPSTEAD, LONG ISLAND, NEW YORK)

The Oceanside Disposal Plant is unique from two different viewpoints: (1) it was the first plant in the United States with continuous feed furnaces to produce steam and electricity from MSW and (2) it is the only mass burning waterwall incinerator in the United States that was originally designed as a refractory wall and then later retrofitted to a waterwall design. The original plant, placed in service in 1965, consisted of one furnace rated at 150 TPD and equipped with wetted baffle walls for gas cooling and cleaning, and two furnaces, each rated at 300 TPD and equipped with forced circulation waste heat steam generators followed by wetted cyclone mechanical dust collectors. Due to excessive particulate emissions and tube failures, these units were subsequently retrofitted. One of the 300-TPD units was retrofitted in 1974 to incorporate a new waterwall furnace/boiler design, and the mechanical collector was replaced with an ESP. An identical modification was performed on the second 300-TPD unit in 1977. The 150-TPD unit remains as a refractory wall incinerator with no heat recovery. The multiclones on this unit have been replaced with an ESP. A summary of the operation and design information about the plant follows.

| | |
|---|---|
| Placed in service: | One unit in June 1974 (retrofit)<br>Two units in June 1977 (retrofit) |
| Design capacity: | 750 TPD (includes two each waterwall units rated at 300 TPD plus a 150-TPD refractory wall incinerator) |
| Current throughput: | 450 TPD |
| Availability: | 50 percent |
| Total amount processed: | 700,000 tons (as of November 1981 and since retrofit) |

| | |
|---|---|
| Receiving: | 10,000 $yd^3$ (two pits with two cranes per pit) |
| Number of lines: | Two each waterwall incinerators plus a third refractory incinerator |
| Grates: | Flynn and Emrick, four-section, rocking grates on two units and a three-section rocking grate on one unit. |
| Boilers: | Two each Erie City boilers with an MCR of 100,000 lb/hr and 460 psig saturated steam, multiple pass, welded wall construction |
| Boiler efficiency: | 62.5 percent |
| Auxiliary burners: | Oil fired, one each per boiler |
| Pollution control: | ESPs, two each Wheelabrator Frye units and one each Precipitaire unit |
| Current emissions: | 0.08 gr/scfm corrected to 12 percent $CO_2$ |
| Product: | 60,000 lb/hr steam (used for desalinization) plus 2,480 kW electricity (for plant use) |
| Capital cost: | $5.25 million for the original plant (1964) plus $2.0 million in 1974 and $3.0 million in 1977 (24.8 million in 1981 dollars) |
| Unit cost: | $33,060 (1981)/TPD |
| Number of employees: | 55 |

The primary factor that has prevented the plant from operating at a higher throughput capacity is the continued maintenance problems with the four desalinization units. Since two of the four units are currently down for repair, only one of the mass burning waterwall units can be placed on-line. A discussion of plant operations, problems, solutions, and recommendations follows.

1. Receiving: At the present plant capacity of 450 TPD, the 10,600 $yd^3$ pit capacity has been found to be adequate. Problems experienced in this area include two or three pit fires and difficulty in securing replacement parts for the cranes.

2. Feed chutes: The throat on the feed chute is currently water cooled with the water flow modulated as a function of throat temperature. In a further attempt to minimize water usage,

consideration is being given to converting to a refractory lined throat.

3. Grates: The four-section rocking grate does a good job of breaking up the refuse. However, an extremely high underfire air is necessary to keep the bed temperatures sufficiently low to prevent slagging. This high underfire air coupled with the rocking motion of the grates results in a high entrainment of ash particulates in the combustion gases. The grates are cleaned every other week with grate replacements currently averaging three per month. A recent seal failure on a hydraulic grate drive cylinder resulted in a spray of hydraulic fluid which was subsequently ignited by a spark from the grate. In view of the significant fire and safety hazard associated with this incident, future hydraulic drive systems should consider using nonflamable hydraulic fluid with the associated compatible hydraulic drive equipment.

4. Refractory wall: The waterwalls are protected by air cooled silicon carbide refractory blocks to a height of 5 ft above the grate and then a 1-in. coating of silicon carbide to a height of 55 ft above the grate (total furnace height is 70 ft). While the silicon carbide blocks initially experienced an overheating problem (which resulted in thermal expansion and shearing of retainer lugs), this problem has been corrected. The refractory has not shown any significant degradation since installation.

5. Slagging: Slagging on the grate was initially a problem until the excess air was increased to 100 percent. As previously discussed, the high underfire air is entraining molten particles which are subsequently quenched around the overfire air ports and on the side walls. The amount of this slagging is so great that the incinerator operation must be restricted to a 7- to 10-day period. It must then be shut down to permit slag removal and general cleaning of the refractory portion of the waterwall.

6. Tube corrosion: It is significant to note that after 7 years of operation on one unit and 4 years of operation on another, there have been no tube failures resulting from corrosion or erosion.

7. Auxiliary burner: Each unit incorporates an auxiliary burner. However, because of the high entrainment of particulates in the furnace, these burners are typically inoperative due to plugging. It was recommended that future designs consider a retractable burner system.

8. Ash handling: The drag chain ash removal system has performed extremely well. During 17 years of operation, the drag chain has only been replaced twice. This long life can be attributed to the slow speed of the conveyor and periodic turning of the chain to distribute wear.

9. Boiler water circulation: While boiler water circulation is currently accomplished by natural circulation, the original design utilized pumping. Circulating the water by pumping was found to be unacceptable when cavitation of a pump and/or loss of power resulted in an emergency situation necessitating immediate action to restore circulation of the boiler water. It was recommended that all future boiler designs incorporate natural circulation of boiler water.

10. Electrostatic precipitators: The ESPs have performed without major problems. Only minor corrosion has occurred as the result of air infiltration through improper seals.

The Oceanside Disposal Plant has a good record of boiler and ESP performance. However, the excessive slagging has severely limited the length of time that each unit can be continuously kept in service. Also, failure of the desalinization units has limited the amount of MSW that can be processed through the plant.

BRAINTREE (MASSACHUSETTS)

The Braintree Thermal Waste Reduction Center is unique in that it is the only municipal waste mass burning waterwall plant in the United States utilizing a traveling grate. During the first 5 years of operation (1971 through 1976), the plant was operated on an 8- to 11-hr, 5- to 7-days per week basis. Continually bringing the unit on and off line resulted in extensive corrosion in the ESPs. After the ESPs were rebuilt in 1976, the plant has essentially operated on a continuous basis. The original plant capacity has recently been recertified from 240 to 384 TPD. Additional operational and design information follows.

| | |
|---|---|
| Placed in service: | May 1971 |
| Design capacity: | 384 TPD |
| Current throughput: | 250 TPD |
| Total amount processed: | 485,000 tons (estimated) |
| Availability: | 85 percent |
| Receiving: | 4500 $yd^3$ (3.7 days of firing at design capacity) |
| Number of lines: | Two each |
| Grates: | Riley stoker, two-section (drying and burning) traveling grate system |

| | |
|---|---|
| Boilers: | Two each Riley boilers with each operating at an MCR of 30,000 lb/hr of saturated steam at 250 psig; single pass with an economizer |
| Boiler efficiency: | 60 percent |
| Auxiliary burners: | One each per boiler, gas fired, 30,000 lb/hr capacity |
| Pollution control: | Two each Wheelabrator/Lurgi ESPs (93 percent collection efficiency, single field) |
| Current emissions: | 0.08 gr/scfm corrected to 12 percent $CO_2$ |
| Product: | Steam (16,000 to 20,000 lb/hr) supplied to industry with the remaining 40,000 lb/hr condensed |
| Capital cost: | $2.8 million (1970) |
| Unit cost: | $17,135 (1981)/TPD |
| Number of employees: | 28 |

The Braintree Thermal Waste Reduction Center has been processing refuse for 10 years without a major outage (with the exception of the ESP overhaul in 1976). All of the tubes and refractory are original. The few tube failures have been noncorrosion/erosion related. A more detailed discussion of the the operating experiences, problems, solution, and recommendations follows.

1. Receiving: The 4500 $yd^3$ receiving pit is too small. It was recommended that future receiving pits for plants of this capacity have a receiving pit with a 6700 $yd^3$ capacity. Also, the bridge crane has been a high maintenance item. A standby crane (not currently installed) should be incorporated into future plant designs to ensure continued operation when the primary crane is down for repair.

2. Feed chute: The original design incorporated a water cooled throat. The feed chute throats were subsequently coated with refractory, and the use of water cooling was terminated. This modification has proved to be successful.

3. Grates: While the traveling grate system provides a well controlled, uniform feed of refuse into the furnace, it is the most labor intensive area (from a maintenance point of view) in the plant. Continuous operation of the incinerator is limited to 1 week due to the need to service the grate cast iron cleats. Typically, each unit is out of service for 8 to 16 hours every other week to permit replacement of broken and damaged cleats. The grate drive system has given excellent service.

4. Refractory: After 10 years of service, the majority of the refractory is still original. There is no slagging or clinkering on the grate or sidewalls.

5. Tube failures: Tube failures have been minimal throughout the 10 years of operation. The two center rows of tubes in the economizer initially experienced repeated stress failures (at the weld joints) and were removed. Also, two or three tube failures have occurred on the sidewall adjacent to the grate. These failures were the result of damage from refuse scraping against the tube surfaces.

6. Soot blowing: Four retractable soot blowers are activated once each shift. There have been no tube failures as the result of cutting from the soot blowers.

7. Excess air: The furnace is typically operated with 100 percent excess air supplied totally as underfire air. The only time that overfire air is used is to reduce smoking.

8. Ash handling: The drag conveyors have provided good service. The drag chains have given 3 years of service before needing replacement.

9. Electrostatic precipitators: As a result of the incinerator units being taken off line on a daily basis during their first 5 years of service life, excessive corrosion occurred in the ESPs. After a complete overhaul, the ESPs have been essentially maintenance free for the past 5 years. During this time, the incinerator units have been operated on a continuous basis.

NAVY PUBLIC WORKS CENTER (NORFOLK, VIRGINIA)

The Navy Public Works Center mass burning waterwall incinerator is unique in that it was the first such installation in the United States. Initial studies were carried out in 1962 with the site becoming operational in May 1967. Specific design and operational data on the facility are as follows:

| | |
|---|---|
| Placed in service: | May 1967 |
| Design capacity: | 180 TPD |
| Current throughput: | 140 TPD |
| Availability: | 50 percent (planned) |
| Total amount processed: | 575,000 tons (as of December 1, 1981) |
| Receiving: | 7600 $yd^3$, 100 ft long by 30 ft wide by 20 ft deep |

| | |
|---|---|
| Number of lines: | Two each |
| Grates: | Detroit Stoker, three-section reciprocating |
| Boilers: | Two each Foster Wheeler welded membrane type boilers with each boiler rated at 50,000 lb/hr (MCR) of 275 psig of saturated steam. |
| Boiler efficiency: | 60 to 70 percent |
| Auxiliary burners: | One each oil fired burner per boiler capable of generating 60,000 lb/hr of steam |
| Pollution control: | Two each ESPs manufactured by Buell, 97 percent collection efficiency |
| Current emissions: | <0.08 gr/scfm corrected to 12 percent $CO_2$ |
| Product: | 45,000 lb/hr of steam for base heating |
| Capital cost: | $2,220,000 (1967), $6,216,000 (1981) |
| Unit cost: | $34,532 (1981)/TPD |
| Number of employees: | 20 |

Since the majority of the refuse burned at this facility comes from military bases, there is an abnormally large amount of paper, cardboard, and wood (total estimated at 70 percent) and other more troublesome wastes such as magnesium, aluminum, waste solvents and paints, tires, and rubber gas tanks. These materials (particularly those with high heat release rates) have been the primary reason for much of the maintenance activities at this facility. An overview of some of the major plant modifications and learning experiences encountered over the past 14 years follows.

1. Receiving: The 7600 $yd^3$ receiving pit is too small. Future installations of this plant capacity should have a receiving pit with 50 percent greater volume. Also, while the bridge crane has performed well, a spare crane is needed as a back-up. The primary problems experienced in receiving is the difficulty in consistently checking the refuse (and removing potentially troublesome items) before shoving it into the pit. During 1979, there was a large pit fire resulting from quantities of methyl ethyl ketone mixed in with the refuse.

2. Feed chutes: After smoothing the weld joints, the feed chutes have performed well with only infrequent jams (due to wooden pallets) occurring in the 4-ft × 8-ft throat.

3. Grates: Typically there are 25 grate section failures each week. This inordinately high number of grate failures has necessitated that each boiler be limited to 1 week of continuous operation followed by 1 week of maintenance. The majority of these grate failures occur on the second (firing) grate. The third grate section (ash removal) typically must be overhauled every 2 weeks while the charging grate can go 18 months between grate changes. Excessive wear has also been experienced with the grate hydraulic drive shaft. There are also frequent jams of the grate due to clinkering. This clinkering also occurs on the air tuyeres between each grate section. It was recommended that operation and life of the grates could be facilitated by utilizing split grate sections with independent hydraulic drives (similar to the charging grate) and elimination of the previously identified troublesome items in the refuse.

4. Refractory: There is no refractory in this furnace. The tubes along the grates are protected from slagging by armored (cast iron) blocks which are bolted to the sidewall tubes at heights varying from 2 to 4 ft above the grate surface. These armored plates must be replaced approximately every 3 months.

5. Tube performance: It is significant that after 14 years of operation the sidewalls, back wall, and roof tubes have not experienced any corrosion. These tubes were ultrasonically gauged in 1976. It was determined at this time that there had been essentially no change in the tube wall thickness (0.150 in.). The convective tube banks were changed in one boiler in 1977 and in the other boiler in 1978. The original convective tube bank went 7 years before a tube failure. The new convective banks have not experienced any failures since installation. Every 45 days the boiler convective tube bank is cleaned with an air lance. This can only be done on one boiler since the other boiler convective tube bank is installed in such a way that it is not possible to insert an air lance between the tubes. No other tube surfaces are cleaned.

6. Soot blowing: There are three each soot blowers in the convective tube bank (two each fixed and one retractable). The retractable soot blower has experienced numerous operational problems. Soot blowing occurs once each shift. Boiler performance would be facilitated if each convective tube bank would have four additional soot blowers (two each in the rear and two each in the middle).

7. Electrostatic precipitators: The ESPs have been subjected to a number of modifications in order to improve performance, i.e., (a) improved inlet air distribution (perforated plates), (b) addition of duct air turning vanes, (c) relocation of the high voltage grids from inside of the ESP to the outside, and (d) installation of an outlet baffle plate. Every 3 months the ESPs are serviced (insulators cleaned and wires aligned).

8. Ash handling: A pusher bar system (connected to the grate drive) under the grates moves the ash shiftings to a wet sump where a drag conveyor transports the ash to a hopper. Typically the drag conveyor must be replaced every 5 years. Also, the ESP fly ash screw conveyor frequently jams.

It is well to note that even with the high maintenance requirements necessitated by the high energy refuse constituents found in military waste, the Navy Public Works Center continues to process 140 TPD of waste and produce 45,000 lb/hr of steam for base heating.

NORFOLK NAVAL SHIPYARD (PORTSMOUTH, VA)

The Portsmouth resource recovery facility is the second of its type built by the U.S. Navy. At a design capacity of 160 TPD, this facility is the smallest waterwall mass burning incinerator in the United States. During the first year of its operation, the plant was operated on an 11 hr/day, 5 day/wk basis. After the first year, additional refuse was secured from the City of Norfolk, and the plant was operated on a continuous basis. Information relative to the plant design and operation is as follows.

| | |
|---|---|
| Placed in service: | August 1977 |
| Design capacity: | 160 TPD |
| Current throughput: | 45 to 55 TPD (continuous) |
| Total amount processed: | 50,000 tons (estimated) as of November 1981 |
| Availability: | 50 percent planned (one unit continuously down); 40 percent actual (the one operational unit typically experiences a 20 percent unplanned down time) |
| Number of lines: | Two each |
| Receiving: | 1900 $yd^3$ (with one each overhead bridge crane) |
| Number of lines: | Two each (80 TPD/line) |
| Grates: | Detroit stoker, three-section, reciprocating grates |
| Boilers: | Two each single pass Keeler boilers, each with an MCR of 30,000 lb/hr saturated steam at 125 psig with an economizer |
| Auxiliary burners: | One each oil fired burner per boiler rated at 30,000 lb/hr |

| | |
|---|---|
| Boiler efficiency: | 66 percent (estimated) |
| Pollution control: | Two each Cambridge single field ESPs |
| Current emissions: | 0.24 to 0.30 gr/scfm corrected to 12 percent $CO_2$ (operating under a variance) |
| Product: | 25,000 lb/hr of 125 psig saturated steam |
| Capital cost: | $4.2 million (1976) |
| Unit cost: | $42,000 (1981)/TPD |
| Number of employees: | 16 |

During the 4 years of operational service, the Portsmouth resource recovery facility has experienced a moderate firing rate demand (one unit operating at 65 to 80 percent of capacity). While these reduced firing rates have tended to minimize equipment failures, there has been sufficient operational experience worth noting. The following paragraphs provide a discussion on these experiences.

1. Receiving: The bridge crane is mounted 180 degrees out of phase. This has created an interference problem which prevents the crane from having complete access to the pit. Also, the closing cable on the crane grapple requires high maintenance (40 hours between failures). A back-up crane is needed to permit operation to continue when the primary crane is being serviced. Also, because of the presence of troublesome materials in the refuse (magnesium, aluminum, solvents, rubber, etc.), considerable effort has to be expended in hand sorting the incoming material. If these materials are not removed, they burn out and/or jam the grates and cause explosions and other problems.

2. Feed chutes: Since the feed chute throat is only 4 ft × 4 ft, jams frequently occur.

3. Grates: While grate replacement is primarily a function of how good a job is done in removing troublesome items, a typical replacement cycle is six to ten grate sections per month (10 to 15 percent of the burning grate). Also, additional problems have been experienced with aluminum which melts and jams the grates and welding rods which fall through the grate and jam up the ash siftings removal door.

4. Slagging and corrosion: Rapid burnout of the armored plates bolted to the sidewall immediately adjacent to the grate necessitated complete replacement with carborundum ceramic bricks. These bricks have shown very little degradation since installation. With the exception of economizer failures (diagnosed as a water

treatment problem), there have been no tube corrosion failures in either boiler. The furnace is typically operated at 30 to 40 percent excess air and temperatures of 1200°F.

5. Soot blowing: There are two fixed and two retractable soot blowers in each unit. Soot blowing occurs two times each shift. Only one tube failure has occurred as a result of soot blowing, and this failure was attributed to improper alignment of the soot blower.

6. Ash handling: The drag chain on one unit was replaced in May 1981, and the other drag chain is currently scheduled for replacement. Other frequent problems include jams and shearing of drive pins.

7. Pollution control: The ESPs have been out of compliance ever since installation. Plans are currently under way to install multiclones ahead of the ESPs.

HAMPTON (VIRGINIA NASA-USAF)

The Hampton facility is one of the more recent waterwall mass burning plants to be brought into operation. Having just recently (September 1981) completed its first year of operation, it represents the latest design and experience with the U.S. mass burning technology. A rather unique feature of the facility is its five-loop control system which permits the incinerators to operate on automatic control 99 percent of the time. This feature will be discussed in more detail later. General information on the Hampton refuse fired steam generating facility is as follows:

| | |
|---|---|
| Placed in service: | September 1980 |
| Design capacity: | 200 TPD |
| Current throughput: | 240 TPD |
| Availability: | 85 percent (planned) |
| Total amount processed: | 71,318 tons (as of October 1, 1981) |
| Receiving: | 1200 tons (5-day supply) with two each overhead bridge cranes (one used in a standby mode) with 3 $yd^3$ grapples |
| Number of lines: | Two each |
| Grates: | Detroit Stoker, the first section is a ram feed and the second and third sections are reciprocating grates |
| Boilers: | Two each Keeler boilers each generating 33,000 lb/hr MCR saturated steam at 360 psig, single pass with an economizer |

| | |
|---|---|
| Boiler efficiency: | 66 percent (estimated) |
| Auxiliary burners: | None |
| Pollution control: | Two each Precipitaire ESPs (2 cell) |
| Current emissions: | <0.02 gr/scfm corrected to 12 percent $CO_2$ |
| Product: | 62,000 lb/hr of 360 psig saturated steam supplied to NASA-Langley |
| Capital cost: | $10.4 million (1979) |
| Unit cost: | $71,760 (1981)/TPD |
| Number of employees: | 31 (plus 9 standbys) |

The fact that the Hampton facility has processed on the average 195 TPD during each day of its first year of operation attests to the success of this project. While sufficient time has not elapsed to provide information on tube life and other equipment having extended life cycles, several design changes have been made and learning experiences have been gained during this first year of operation. The following paragraphs summarize the major points.

1. Receiving: At 1200 tons capacity, the receiving pit is large enough to permit movement of the refuse through the pit on a first in, first out basis. By clearing the pit to the floor once each week, odors are minimized and pit fires are eliminated. Some difficulties have been experienced with mechanical failures of the crane grapple.

2. Feed chute: The feed chutes to the incinerators have been the primary source of problems at the Hampton plant. The chutes were designed with a vertical refuse feed with a sharp right turn of the duct at the in-feed to the reciprocating grate. This design configuration subsequently had to be modified when the compression loading of the refuse in the vertical feed chute prevented the reciprocating grate from feeding refuse onto the firing grate. This problem was corrected by replacing the reciprocating grate with a hydraulically actuated ram feed. While this configuration permitted refuse to be fed onto the firing grate, the feed rate was nonuniform. This problem is currently being rectified (one incinerator complete and the other scheduled for modification in the near future) by relieving the roof over the ram feed where it connects to the vertical feed chute.

3. Grates: All of the grates in the firing section and half of the grates in the ash section must be replaced every 6 months. Also, the vertical tuyeres between each grate section were experiencing rapid burnout and had to be replaced with a chrome alloy type material.

4. Boiler tubes: The National Bureau of Standards recently inspected and ultrasonically gauged the thickness of the boiler tubes. After 1 year of service, there is no evidence of corrosion or measurable change in tube thickness. Soot blowing with five retractable and two fixed soot blowers occurs twice each day. The furnace is maintained at 1550°F and 80 percent excess air.

5. Controls: The five control loops at the Hampton resource recovery facility is unique in that they permit incinerator operation to be maintained in an automatic mode 99 percent of the time. This contrasts with other mass burning sites where operation is typically a combination of both automatic and manual modes. The control loops which enable this automatic mode are as follows.

    1. Three-element feedwater
    2. Constant furnace pressure
    3. Ram feed and underfire air
    4. Constant boiler pressure
    5. Heat release rate compensation

    While Control Loops No. 1 and 2 are common in steam plants, loops No. 3, 4, and 5 are unique to the Hampton plant.

6. Auxiliaries: All pumps and fans throughout the plant incorporate double-ended shafts and are coupled to both electric and steam drives. A recent failure of a feedwater pump which resulted in an extended boiler outage emphasized the need for having spare feed pump capacity.

7. Maintenance: Each spring and fall one of the two mass burning waterwall incinerators is shut down 1 month for maintenance. Recently unplanned outages have been running 5 to 10 percent on one boiler and 15 to 30 percent on the other.

MONTREAL (QUEBEC)

The City of Montreal Municipal Incinerator, placed in service in September 1970, represents the first Von Roll system in North America. The other two operating systems are located at Quebec, Providence of Quebec, and Saugus, Massachusetts. Having recently completed 11 years of successful operation without a major operational outage, this facility represents an excellent example of mass burning waterwall technology. Specific information related to the design and operation of the plant is as follows.

| | |
|---|---|
| Placed in service: | September 1970 |
| Design capacity: | 1200 TPD |
| Current throughput: | 950 to 1000 TPD |
| Total amount processed: | 3,100,000 tons (as of November 1981) |

| | |
|---|---|
| Availability: | 85 percent |
| Receiving: | 12,000 $yd^3$ with two each traveling cranes |
| Number of lines: | Four each |
| Grates: | Von Roll reciprocating |
| Boilers: | Von Roll (Eckrohr type) with an MCR of 100,000 lb/hr steam flow at 225 psig and 500°F, three pass with superheater, economizer, and air preheater |
| Boiler efficiency: | 67 percent |
| Auxiliary burners: | One each oil fired burner per furnace rated at 50,000 lb/hr of steam |
| Pollution control: | Research Cottrell ESP (95 percent collection efficiency with two fields) |
| Current emissions: | 0.08 gr/scfm corrected to 12 percent $CO_2$ (at 75 percent of plant capacity) |
| Product: | Steam, 360,000 lb/hr (36,000 lb/hr supplied to industry, the rest is condensed and/or exhausted to atmosphere) |
| Capital cost: | $15 million (1969) plus $9.5 million (1982) |
| Unit cost: | $29,556 (1981)/TPD |
| Number of employees: | 76 |

While the Montreal waterwall mass burning incinerator system has worked well, the air pollution control system has been a continuing problem. Whenever the plant is operated near capacity, large amounts of particles (char) are emitted out the stack. A discussion of the proposed solution to this problem along with a general overview of the plant's operational and maintenance experiences follows.

1. Receiving: The 12,000 $yd^3$ receiving pit has adequate capacity, and the cranes have performed well. However, there is a dust problem which is currently being addressed.

2. Grates: The grate system consists of three sections: feeding, burning, and finishing. Grate life on the feeding section is estimated to be 20 years while the burning and finishing grates having a demonstrated 7- to 8-yr life. Every 4 to 5 months, one

or two grates are replaced. In order to facilitate maintenance, modifications were made to the grates to make them all the same length.

3. Refractory: Difficulties were initially experienced with failure of the stainless steel anchor pins securing the silicon carbide bricks and alumina coating to the waterwall. Proper heat treatment of these anchor pins has subsequently solved this problem. Otherwise, degradation of the refractory has been minimal.

4. Tube corrosion and fouling: There have been very few tube corrosion and/or erosion problems. The only place that corrosion has been experienced is in the economizer section. Tube fouling and/or plugging of the gas passages in the convective and superheat sections have been a continuing problem. Every 14 weeks the convective section must be washed with high pressure water. This problem is being corrected by increasing the tube spacing from 2 1/2 in. to 6 in.

5. Soot blowing: Because of the tube fouling problem, a double soot blowing occurs every 4 hours. There are three retractable and ten fixed soot blowers per boiler.

6. Excess air: The furnace is typically operated with 50 percent excess air supplied totally as underfire air. Consideration is being given to installing a carbon monoxide emission monitoring system which would modulate the excess air system.

7. Pollution control: As previously indicated, the major problem at the plant is particulate emissions. The boilers must be operated at a reduced capacity, 75,000 lb/hr, in an attempt to minimize the amount of emissions. During 1982 this problem will be corrected by installing on each boiler a cyclone and a three-stage low velocity ESP. Consideration is also being given to a dry limestone scrubber to control HCl emissions at less than 500 ppm.

QUEBEC (QUEBEC)

The City of Quebec Municipal Incinerator is very similar in design to the Montreal plant with the exception that it has a slightly lower throughput capacity. One attractive feature of this plant is that it has an ash pit which permits ash removal to be carried out on a 40-hr work week, day-shift basis. Most other plants (which do not have this capability) are required to commit trucks and personnel to ash removal on a continuous bases. Additional design and operational information on the plant is as follows:

| | |
|---|---|
| Placed in service: | Two each in 1974<br>Two each in 1975 |
| Design capacity: | 1000 TPD |

| | |
|---|---|
| Current throughput: | 650 TPD |
| Availability: | 75 percent |
| Total amount processed: | 1,458,000 tons (as of December 1981) |
| Receiving: | 13,000 $yd^3$ with two each bridge cranes (4 $yd^3$ grapples) |
| Number of lines: | Four each |
| Grates: | Von Roll reciprocating |
| Boilers: | Four each Von Roll designed boilers with each boiler having an MCR of 80,000 lb/hr (680 psig and 600°F) steaming capacity; the design incorporates a superheater and an economizer |
| Auxiliary burners: | Not in use |
| Pollution control: | Four each Research Cottrell ESPs (two field, 98.5 percent collection efficiency) |
| Emissions: | 0.02 gr/scfm corrected to 12 percent $CO_2$ |
| Product: | Steam, 130,000 lb/hr, supplied to a paper mill |
| Capital: | $27 million (1973) |
| Unit cost: | $59,400 (1981)/TPD |
| Number of employees: | 55 |

During the first 2 years of operation of this facility, problems with the grate metallurgy created numerous outages and reduced throughputs. A discussion of this problem and other general operational data follows.

1. Receiving: The truck unloading platform is in the wrong location. Trucks unload at the 52-ft level with the top of the refuse pit at the 85-ft level. Failure to locate the truck unloading at the top of the pit necessitates moving the refuse twice before introduction into the feed chutes.

2. Grates: The original grates were supplied with a chrome alloy material. This alloy proved to be highly susceptible to mechanical failures and thermal fatigue. Subsequently, changing the alloy on all the moving grates to a 2 percent nickel, 25 percent chrome alloy corrected this problem.

3. Refractory wall: Silicon carbide refractory blocks are installed to a 1-ft height above the grate. A plastic refractory is then utilized to cover the walls to an 8-ft level above the grate. Clinker formation on these sidewalls has been a continual problem. Sprinklers have been installed and utilized to minimize clinker formation. Every 2 months the incinerator must be taken off line for removal of the clinker formations on the furnace walls.

4. Tube erosion/corrosion: All tube failures to date have occurred in the first three or four panels of the convection bank. After the initial failures in 1976, the problem was corrected by coating the tubes with a refractory material.

5. Excess air: Excess air is typically maintained at 85 to 100 percent utilizing both underfire and overfire injection.

6. Ash handling: The drag conveyors have performed well with the original chain still in use. As previously indicated, the ash pit design significantly reduces the cost of this operation.

## OBSERVATIONS AND RECOMMENDATIONS

In reviewing the overall operational and maintenance experience of mass burning waterwall systems, some general observations can be made with regard to recurring problems and recommendations for future plants. The following paragraphs present a summary of these observations and recommendations.

1. Preprocessing: While incoming refuse must be closely monitored to remove those items which would cause jams, explosions, or grate burnout, the use of shredders to reduce bulky items in size has been found to be unnecessary.

2. Receiving pits: The majority of plants are designed with receiving pits that are too small. A 5- to 7-day capacity receiving pit is preferred. Also, the receiving pit should provide access for cleaning floor drains. The bridge cranes should be remotely controlled with a programmed stacking capability. Care should be exercised to ensure that crane cables and grapples have adequate strength to provide the desired operational life cycle.

3. Feed chutes: Care must be exercised to ensure that throat sizes are large enough and the feeding angle is such that jams will not occur. Consideration should be given to utilizing refractory lined feed chutes (eliminating the need for cooling water).

4. Grates: The European grates have clearly demonstrated that they have a much longer maintenance life than the U.S. grates. European grates have demonstrated a grate life of 7 to 8 years while U.S. grates are typically less than a year. It should be noted however, that all grate systems require periodic maintenance. A reciprocating or rocking grate design inclined at an angle of 20 to 25 degrees

appears to provide the required mixing and tumbling of the refuse to ensure complete burnout. Plant safety can be facilitated by designing the grate hydraulic drive system to accommodate nonflammable hydraulic fluid.

5. Furnace/boilers: The furnace volume and location of overfire air jets must be modeled to ensure that proper combustion kinetics are achieved. Acceptable tube life can be achieved by utilization of silicon carbide brick or air cooled ceramic plates on the furnace walls immediately adjacent to the grate and a 1-in. silicon carbide plastic refractory coating approximately one-half the height of the furnace walls. Extended superheater tube life can be achieved by locating the superheater in the second or third pass of the boiler. Consideration should also be given to increasing the tube thickness over that required by the ASME standards. Tube spacings in the convective section should be at least 6 in. to prevent plugging and to facilitate cleaning. Soot blowers should be carefully positioned and condensation removed from the steam line to prevent cutting of tubes during the soot blowing operation.

6. Ash handling: The ash handling and grate system have been the two most labor intensive subsystems in the mass burning waterwall system. In reviewing the various ash handling systems, it is apparent that this operation can be greatly facilitated (operating and maintenace costs reduced) by utilization of a wet sump drag chain conveyor and an ash pit design. The ash pit would have sufficient capacity to permit operation only on a 40-hr, single-shift basis.

7. Operations: It has been found to be essential to have a well trained operational staff. The crane operator must possess the knowledge and skill required to properly feed the incinerators. The boiler operator and control room operator must closely monitor the combustion in the incinerators and adjust the underfire/overfire air and excess air to achieve the desired combustion conditions, i.e., 80 to 85 percent excess air with no reducing atmospheres and/or flame impingement on the tube surfaces. Close communication must be maintained between each of the operators at all times.

8. Redundancy: Because municipal waste is a heterogeneous material that often creates problems in handling and combustion, the plant must be designed with complete redundancy capability. This includes such considerations as (1) sufficient plant capacity to permit implementation of a well planned preventive maintenace program, i.e., a planned plant capacity availability of 80 to 85 percent; (2) a spare bridge crane; (3) spare feedwater pumps; (4) demineralizer systems designed for 150 percent of required capacity; and (4) double ended drive shafts on all prime movers with both electric and steam turbine drives.

9. Preventative maintenance: A well planned preventive maintenance program is essential to achieving successful plant operation. Such a program cannot be implemented, however, if the aforementioned redundancy is not designed into the plant. The facility should incorporate a fully equipped maintenance shop with skilled personnel to run it. A complete supply of replacement parts (grates, boiler tubes, pumps, motors, etc.) must be available at all times.

## FUTURE MASS BURNING FACILITIES

There are currently 11 mass burning waterwall systems in various stages of development in the United States (see Table 3). These facilities, representing a potential installed capacity of 16,960 TPD, are almost totally dominated by the European systems licensed by Wheelabrator-Frye and UOP. A single exception is the water cooled rotary kiln employed in the Gallatin, Tennessee, project. This design is a departure from the conventional inclined grate, waterwall furnace design utilized in the Josef Martin and Von Roll systems.

The Gallatin, Tennessee, and Pinnelas County projects are the only two projects under construction. Westchester County, New York; Baltimore, Maryland; and Portland, Oregon, should all initiate construction activities during 1982. The remainder of the projects are in various stages ranging from finalizing negotiations, selecting a site, securing contracts for the waste, financial planning, securing permits, etc. It is well to note that in practically every project saleable electricity is a principal product. This capability attests to an anticipated plant availability similar to conventional power plants. The average capital cost of 1 TPD for these new plants is $60,000 (excluding the Portland project). This compares with an average capital cost of $43,200 for 1 TPD in the currently operational plants (see Table 1). A brief status report on each of these plants follows.

### Pinellas County (Clearwater, Florida)

The Pinellas County project is currently the only large (2,000 TPD) mass burning waterwall incinerator under construction in the United States. It is presently 40 percent completed, with start-up scheduled for August 1983. The plant consists of two Josef Martin units, each rated at 1,050 TPD. Refuse is received in a 7,000-ton capacity receiving pit and burned on the Martin reverse acting, reciprocating, stoker grates. The Riley Stoker boilers, each rated at 135,000 lb/hr, 615 psig, 750°F superheated steam, supplies a turbo generator which in turn generates 50MW of electricity. The boilers do not incorporate auxiliary burners. Pollution control is accomplished by two each UOP electrostatic precipitators rated at 98.5 percent collection efficiency. A unique design feature of the Pinellas County facility is that the 1.8 million gallons per day (MGD) of cooling water is supplied from the tertiary effluent from St. Petersburg's wastewater treatment plant.

An often overlooked but necessary part of every mass burning resource recovery project is the support contracts. In addition to the basic

TABLE 3. A SUMMARY OF U.S. MASS BURNING WATERWALL SYSTEMS IN CONSTRUCTION AND/OR PLANNING

| Site location | Capacity (TPD) | Number of lines | System designer | Status | Projected start-up | Product | Cost (1981) Facility ($ millions) | Cost (1981) Unit ($/TPD) |
|---|---|---|---|---|---|---|---|---|
| Pinellas County, FL | 2000 | 2 ea. | UOP | Construction | August 1983 | 50 MW electricity | 109 | 54,500 |
| Westchester County, NY | 2250 | 3 ea. | Wheelabrator-Frye | Design | January 1985 | 55 MW electricity | 175 | 77,800 |
| Baltimore, MD | 2010 | 3 ea. | Wheelabrator-Frye | Financial planning | April 1985 | 40 MW electricity | -- | --- |
| Portland, OR | 1600 | 3 ea. | Wheelabrator-Frye | Negotiations | Fall, 1985 | Steam - 300,000 lb/hr | 170 | 106,250 |
| North Andover, MA | 1500 | 2 ea. | UOP | Securing waste | July 1985 (est.) | 35 MW electricity | 74 | 49,333 |
| 128 West Project, MA | 1500 | 2 ea. | Wheelabrator-Frye | Securing waste | October 1985 (est.) | Electricity | -- | --- |
| Onondaga County, NY | 1400 | 2 ea. | UOP | Financial planning | January 1985 | Steam - 140,000 lb/hr and 32.2 MW electricity | 77.6 | 55,465 |
| Brooklyn Navy Yard, NY | 3000 | 4 ea. | UOP | Negotiations | 1986 | Steam - 133,000 lb/hr | 226 | 75,333 |
| San Francisco, CA | 1500 | 2 ea. | Final selection | Pre-bid negotiations | 1986 | Electricity | -- | --- |
| Providence, RI | 1500 | 2 ea. | Widmer & Ernst | Financial planning | 1986 | Electricity | -- | --- |
| Gallatin, TN | 200 | 2 ea. | O'Connor | Start-up | January 1982 | Steam - 54,000 lb/hr and 550 kW electricity | 9.4 | 47,000 |

$109 million (1981 dollars) construction contract with UOP Incorporated, Pinellas County has awarded $8 million dollars (1981) in 22 support contracts. These contracts encompass such varied tasks as construction of an electric transmission line, roads, an office building, a scale house and associated computer system, a storm water collection and spray irrigation system, a sanitary sewer pumping station, embankment and landscaping, a potable water supply, and transfer stations.

Revenue is generated by (1) tipping fees (46 percent of the income); (2) the sale of electricity to Florida Power Corporation (38 percent of the income); (3) the sale of ferrous, aluminum, heavy nonferrous, and glass aggregate (8 percent of the income); and (4) interest earned on the reserve funds on deposit (8 percent of the income). The project was funded with $160 million worth of Industrial Development Bonds secured by the revenues from the system and backed by the Non-Ad Valorem Funds of Pinellas County.

Gallatin (Tennessee)

This facility is unique in that it represents a new approach to mass burning and is the first such facility in the United States. The facility, owned by the Sumner County Resource Recovery Authority, consists of two O'Connor waterwalled rotary kiln incinerators with a combined capacity of 200 TPD. In addition to the waterwall kilns, two each waterwall boilers produce a total of 54,000 lb/hr of steam at 400 psig. A turbogenerator is also available to produce 550 kW of electricity. Each 100-TPD system is estimated to reduce waste volume by 90 percent with a thermal efficiency of 80 percent. Advantages of this system include (1) elimination of refractory and burning grates which are required in the more conventional mass burning waterwall systems and (2) higher boiler efficiency. Successful operation of three similar facilities in Japan and Taiwan have demonstrated the reliability of this design. While the throughput capacity cannot be compared with the 1500- to 3000-TPD mass burning plants currently in design and construction throughout the United States, it does offer a possible alternative to the smaller size communities.

The $9.4 million installed cost was totally financed with revenue bonds. A total of 19 people are expected to operate the plant when it starts up in early 1982.

Westchester County (New York)

Wheelabrator-Frye Inc. was awarded a contract in June 1981 to construct a 2,250-TPD (3 lines, each rated at 750 TPD) Von Roll mass burning waterwall incinerator system in Westchester County, New York. This facility, producing 526,000 lb/hr of 850 psig and 825°F superheated steam, will generate and sell 55 MW of electricity to Consolidated Edison of New York. The $175 million dollar (June 1981) facility will be financed by (1) $93.5 million in industrial revenue bonds issued by the State Industrial Development Agency, (2) $27.5 million in State environmental quality bonds, and (3) $54 million in equity supplied by Wheelabrator-Frye. The design of this facility is under

way with the financing plan and permits nearly completed. Construction is scheduled to be initiated in February 1982 with plant startup scheduled for January 1985. Wheelabrator-Frye will operate the plant under a 20-yr contract.

Portland (Oregon)

Negotiations are currently being finalized with Wheelabrator-Frye to design and construct a 1,600 TPD mass burning waterwall incinerator facility. Preliminary design of the facility specifies three each Foster Wheeler boilers rated at 670 TPD, 150,000 lb/hr MCR steam at 650 psig and 700°F. Each boiler is expected to operate at 60 to 70 percent of MCR with 300,000 lb/hr of steam being sold to Publishers Paper Company. The receiving pit will have a 6,000-ton capacity. The reciprocating grates will be supplied by Von Roll, Ltd. It is anticipated that the facility will have a planned availability of 80 percent. Total capital cost for the facility is $170 million with 3 years allocated for construction.

San Francisco (California)

This 1,500-TPD project is currently in the prebidding stage with Wheelabrator-Frye and Combustion Engineering as the final two contractors. Since each contractor has a different system design, the final evaluation will provide interesting comparative technical and economic data between a mass burning waterwall system and a refuse-derived fuel (RDF) suspension fired boiler. Other factors which make this project unique are (1) restrictive air pollution control regulations necessitating the use of a dry scrubber and a baghouse, (2) the requirement for dry cooling towers (closed loop cooling system) to condense the steam from the turbogenerators (made necessary by the need to conserve water), and (3) restrictive ash disposal regulations which require that the residue be treated as hazardous waste. Since hazardous waste must be disposed in a Class 1 landfill having disposal fees of $175/ton, a front end trommel processing line has been incorporated into the facility design in an attempt to minimize the ash residue tonnage. The contract award is scheduled for May 1982 with negotiations and a 33-mo construction period to follow.

North Andover (Massachusetts)

In 1975, UOP, Inc., was awarded a contract to design, construct, and operate a 1,500-TPD (2 lines, each rated at 750 TPD) Martin mass burning waterwall system. The plant is being designed such that the capacity can be increased to 3,000 TPD at some future date. Considerable effort has been expended to secure service agreements with 20 communities in northeastern Massachusetts and southern New Hampshire. The goal is to secure agreements for 900 TPD of municipal waste with an additional 600 TPD reserved for private haulers. To date, commitments for 600 TPD have been received. The facility will generate 35 MW of electricity which will subsequently be sold to the New England Electric Power Company. The $74 million (October 1980 dollars) capital cost is being totally financed by revenue bonds (the majority of which

are tax exempt). With financing scheduled for completion on June 30, 1982, and 3 years allowed for construction, start-up should occur in July 1985.

The project is unique in that it is the first in the United States that was established without a central authority. Community participation has been solicited on a voluntary basis. Tax benefits are being offered to the communities based upon a special credit equivalent to a leveraged lease with 28 1/2 percent equity.

128 West Project (Massachusetts)

In August 1980, Wheelabrator-Frye was selected as the contractor to design and construct a 1,500-TPD mass burning waterwall incinerator to be located at a site immediately adjacent to a landfill in Plainville, Massachusetts. The facility's output will be electricity supplied to the New England Power Company. The status of the project is similar to North Andover in that negotiations are currently under way with 40 communities to secure contracts for the solid waste.

Onondaga County (Syracuse, New York)

Contract negotiations are currently in process with UOP, Inc., to design and construct a 1,400-TPD (2 lines, each rated at 700 TPD) Martin mass burning waterwall system. This will be a co-generation facility with 140,000 lb/hr of steam supplied to Syracuse University and the County via a 3 1/2-mi steam line and 32.2 MW (peak capacity) of electricity. Efforts are currently under way to secure commitments for the City of Syracuse municipal waste. The County is guaranteeing 330,000 TPY of refuse with a maximum of 420,000 TPY (1,150 TPD). Financing is scheduled to be completed by April 1, 1982, with 33 months allocated for construction (start-up January 1985). The facility cost is $77,652,000 (as of June 1981).

Brooklyn Navy Yard (Brooklyn, New York)

UOP, Inc., has just recently been selected to design and construct a 3,000-TPD (4 lines, each rated at 750 TPD) Martin mass burning waterwall system. This system will produce 20,000,000 lb/day (833,000 lb/hr) of superheated steam (465 psig, 473°F) which in turn will be sold to the Consolidated Edison Company. Electric power will also be generated for in-plant use. The facility will be unique in that it will be the first barge fed mass burning system in the United States. The $226 million capital cost is being financed by (1) a State grant, (2) City revenue bonds, (3) City capital funds, and (4) private equity. Allowing 39 months for construction, the facility is scheduled to be placed in operation in 1986. UOP will be the plant operator.

Baltimore (Maryland)

The Northeast Maryland Solid Waste Authority is currently in the process of awarding a contract to Wheelabrator-Frye to construct and operate a 2,010-TPD (3 lines, each rated at 670 TPD) mass burning waterwall incinerator.

The new incinerator will be sited at the Baltimore pyrolysis plant location. Each of the boilers will supply 180,000 lb/hr of steam to a turbogenerator which will in turn supply 40 MW of electricity (14 percent retained for in-plant use) to Baltimore Gas and Electric. Stringent air regulations require the use of four-field, 99.8 percent collector efficiency, Wheelabrator-Lurgi ESPs. The plant will be funded by 27.5 percent equity from Wheelabrator-Frye, and the balance will be loaned to Wheelabrator-Frye from the proceeds of a revenue bond sale. Construction is scheduled to begin in June 1982 with start-up planned for April 1985.

Providence (Rhode Island)

In 1979 Widmer & Ernst was selected by the Rhode Island Solid Waste Management Authority as the contractor to construct a 1,500-TPD mass burning waterwall incinerator located in the City of Cranston, Rhode Island. This site was subsequently rejected in favor of two other sites located at Johnston landfill and the community of Warwick. Efforts are currently under way to complete the financing plan by September 1983 with construction commencing in the spring of 1983.

## LEGAL, FINANCIAL, AND INSTITUTIONAL FACTORS

If everything goes well, most solid waste authorities involved in the development of large resource recovery projects indicate that 6 to 7 years is required from project inception to facility start-up. Perhaps the toughest part of such a project is the 3 to 4 years of legal, financial, and institutional work required before construction can commence. Some of the more challenging tasks that have the potential for introducing design delays and/or canceling a resource recovery project include (1) securing contracts for the required amount of refuse, (2) selecting an acceptable site, (3) securing the necessary permits, and (4) establishing a financial plan that is acceptable to all parties. Securing the waste streams can involve negotiation and legal actions with 20 to 30 governmental entities and private haulers. Selecting an acceptable site involves both technical and political issues which must in turn be properly presented to the local community to gain their support. Securing permits can be an overwhelming process, i.e., the Saugas project required 18 permits from 9 state agencies and 4 permits from the federal government. Establishing an acceptable financial plan requires selecting a bonding authority and type of financing; negotiating with the plant operator such matters as investment tax credits, depreciation allowance, local property taxes, tipping fees, etc.; and establishing a trust indenture which protects the bond holders and controls the flow of funds. All of these efforts typically occur after contractor selection and can require 2 to 3 years. Efforts prior to contractor selection can be equally demanding. They include a feasibility study, securing an energy market, characterizing the waste stream, preparing of the Request for Proposals (RFP), and evaluation of the responses.

There is little wonder that most solid waste authorities feel a great sense of relief upon completing the aforementioned complex and involved tasks. With this work accomplished, the 3-yr construction period can commence.

## The Future of Mass Burning in the United States

With an installed capacity of 8,114 TPD and an additional 16,900 TPD scheduled to be operational by 1986, the future for mass burning waterwall technology looks bright. There are several factors which are kindling enthusiasm for this technology.

- The "learning experience" phase should now be complete and U.S. industry can now provide proven and reliable resource recovery systems
- Sanitary landfills are becoming increasingly expensive and difficult to site as regulations become more stringent
- Energy prices are making large mass burning systems with co-generation (taking advantage of PURPA) more attractive
- The estimated 200 million TPY of refuse available in 1985 represents a major untapped and reliable energy resource available to municipal planners
- U.S. municipalities are now more willing to enter into cooperative financial ventures with industry

To date, the 11 operating U.S. and Canadian mass burning systems represent a total of 91 years of mass burning experience. This experience is operational evidence that municipal refuse can be disposed in both an environmentally acceptable and energy efficient manner.

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